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II. *Analysis of a Meteoric Stone which fell near Adair, in the County of Limerick, on September* 10, 1813. *By* JAMES APJOHN, M.D., M.R.I.A., *Professor of Chemistry in the Royal College of Surgeons in Ireland.*

Read 23rd May, 1836.

THERE is no natural phenomenon more calculated to excite astonishment, or which has actually caused more surprise, than the fall of heavy bodies through the atmosphere. For a length of time the fact was altogether denied by the highest authorities in science, and the strongest evidence resisted, when adduced in support of an event which was conceived repugnant to the laws of nature. Philosophic incredulity, though generally useful, was, in this instance, carried too far, and proved injurious to the progress of science; for while doubts were entertained concerning the reality of stony showers, the sources of the aeroliths and their nature were not, of course, likely to be made objects of investigation. The occasional occurrence, however, of such a phenomenon having been at length established by incontrovertible testimony, the questions just alluded to were eagerly discussed, but by no means with the same degree of ardour or success. A multitude of hypotheses were almost immediately broached in reference to the origin of meteoric stones, but philosophers were more slow in applying themselves to the analysis of these singular bodies, though it might have been easily foreseen that a knowledge of their constitution and properties would, if not essential as a preliminary to the investigation, be at least very useful in all attempts to trace them to their origin. Mr. Howard, indeed, as is well known, was the first competent person who devoted himself to this latter research, and after an analysis of four distinct specimens of aeroliths, and as many of native iron, he was enabled to announce to chemists the following facts in reference to their composition:—

1st. That meteoric stones always contain an alloy of iron and nickel, the amount of which is subject to variation.

2nd. That they contain a sulphuret of iron decomposable by muriatic acid.

3rd. That they contain an earthy matrix consisting of silex, magnesia, and oxide of iron.

4th. That the above-mentioned alloy of iron and nickel is identical with native iron.

5th. That the earthy matter sparingly attached to native iron is of the same nature with the matrix of meteoric stones.

To these results of Howard, Laugier made an important addition by the discovery of chrome as a component part of some aeroliths which he submitted to chemical examination.

From these sources alone, namely, the essay of Howard, and the paper just mentioned by Laugier, was any knowledge I possessed on the subject of the composition of aeroliths derived up to the time of my entering upon, and in a great measure completing the analysis of the specimen, to which I shall now proceed to draw the attention of the Academy.

The stone in question was given me by my friend, Daniel Reardon, Esq., of this city, and is one of a shower which fell near Adair, in the county of Limerick, in the year 1813. The shower is mentioned in Chladni's Catalogue, who states that one of the stones weighed eighteen pounds, and refers for further particulars to the Philosophical Magazine and Gentleman's Magazine of that period. I have looked carefully through the former journal for 1813, and the seven subsequent years, but have not been able to find the account referred to by Chladni. But in the Gentleman's Magazine for 1813, part 2, page 390, the following brief notice of the phenomenon occurs:—

"At Adair, county of Limerick, six o'clock in the morning, a shower of stones is stated to have fallen from a thunder cloud, extending about a mile and a half, with a sound like the discharge of artillery, followed by a noise resembling the rolling of drums. The air heavy and hot—several loud explosions—no lightning. Several of the stones weighed from one to four pounds. They are black outside, extremely heavy, much burned, and when broken of a dingy grey."

The mineralogical characters of the stone in my possession are so similar to those assigned by the Count De Bournon to the specimens examined by Howard, that a very cursory notice of them will be sufficient here. The weight is 1½ lb.

avoirdupois, its shape that of an irregular parallelepiped, and it is covered externally with a thin fused crust, of a dark colour, and sufficiently hard to strike fire with steel. When broken, the interior exhibits a pale yellow or greyish colour, and the surface of the fracture presents, particularly when examined with a lens, a number of metallic points, and two or three minute particles of what would appear to be iron pyrites. Its specific gravity is subject to variation, no doubt because of the metallic constituents being dispersed unequably throughout the mass. Thus, the portion first examined had a specific gravity of 4.230, while the density of another fragment of the stone reached but 3.621. When presented by any of its faces to a horizontal needle, attraction always took place, showing that it is susceptible of magnetism, but destitute of any permanent polarity.

By a number of preliminary experiments, the particulars of which it is not necessary to detail here, it was ascertained that the stone was composed of the following proximate constituents :—

1st. Native iron alloyed with nickel and cobalt.

2nd. Sulphuret of iron, soluble in muriatic acid.

3rd. Chrome iron ore.

4th. An earthy, or more probably two earthy minerals, composed of silex, magnesia, protoxide of iron, with traces of alumen, lime, and the oxide of manganese.

It was not examined for an alkali.

The quantative analysis was conducted as follows :—

Two hundred grains were reduced to a fine powder, and then treated with nitromuriatic acid, which dissolved the iron with the copious evolution of nitric oxide, and at the same time developed sulphur and gelatinous silex; the former proceeding from pyrites, and the latter from the matrix of the stone. When, by the repeated additions of fresh portions of aqua regia, and a prolonged digestion, the sulphur was altogether acidified, the whole was evaporated to dryness, to render the silex insoluble, again acidulated with muriatic acid, and finally, distilled water being previously added, thrown upon a double filter. The matters detained by this were then repeatedly washed, by which the 200 grains of meteorite under experiment were resolved into a soluble portion (A), and an insoluble portion (B.) To the solution (A) chloride of barium was added, as long as there was any precipitate; and the sulphate barytes collected on a double filter, well washed, and dried upon the edge of the sand bath, weighed 21.88 grains,* equivalent, as may be easily calculated, to three grains of sulphur, or 8.25 sulphuret of iron, provided the pyrites present be a binary compound.

To the washings of the sulphate of barytes, sulphuric acid was added, so as to throw down any excess of barytes used, and the whole having been passed through a single filter, a mixture of muriate of ammonia and water of ammonia was poured in until the latter became predominant in the fluid. The peroxide of iron thus precipitated, being collected on a double filter, washed, and dried on the edge of the sand bath, weighed 127.01 grains. Of this, 123.07 grains were solved in muriatic acid, and then boiled with a considerable excess of potash, which again threw down the iron; and the alkaline solution, upon examination in the usual manner, was found to contain a trace of alumen, which, however, was too insignificant to be weighed. The peroxide of iron collected on a double filter, washed and dried, was found to weigh 107.26 grains; and 106.16 of this, exposed to a red heat, were reduced to 78.73. Hence,

106.16 : 78.73 : : 107.26 : 79.54, and

123.07 : 79.54 : : 127.01 : 82.08 = peroxide of iron, in the solution (A), corresponding to 57.95 metallic iron.

To the solution deprived of the iron by ammonia, and which exhibited a greenish blue colour, hydro-sulphuret of ammonia was added, and the black precipitate formed (sulphuret of nickel) was washed upon a single filter. It was then transferred to a porcelain capsule, decomposed by nitro-muriatic acid, filtered, to separate the sulphur, and then precipitated by caustic potash. When washed upon a double filter and dried, the oxide of nickel weighed 4.39 grs. Of this 4.05 grains were exposed to a red heat, and thus reduced to 2.67. Hence,

4.05 : 2.67 : : 4.39 : 2.89 = the exact amount of the oxide of nickel, and which is equivalent to 2.28 metallic nickel.

The washings of the sulphuret of nickel were now treated with oxalate of ammonia, which threw down oxalate of lime amounting after desiccation at 212°

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* The barytes was perfectly dry; for by exposure to heat it suffered no further loss.

to 1.58 grs.; of this 1.07, heated to low redness, gave .63 of carbonate of lime. Hence,

1.07 : .63 : : 1.58 : .93 carbonate of lime, equivalent to .52 of lime.

The solution deprived of the lime was treated with carbonate of potash, added in considerable excess, and then evaporated to dryness. Water was now poured on, and the carbonate of magnesia which remained was collected, and well washed upon a double filter. When dried on the sand bath, it weighed 42.79 grs. 42.58 were exposed to a red heat, and reduced to 18.60. Hence,

42.58 : 18.60 : : 42.79 : 18.69 the magnesia.

The following therefore are the results of our analysis of solution (A.)

Sulphuret of Iron . . .	Sulphur . 3 Iron . . . 5.75	8.75
Iron=57.95 — 5.75=		52.20
Nickel		2.28
Magnesia		18.69
Lime		.52
		82.44

In this statement the whole of the iron is estimated in the metallic state. A part of it, however, is present as protoxide in the earthy matrix decomposed by the acids, and to determine the relative proportions of it in these two states, it is only necessary to know the total weight of the portion of the aerolith solved by the acids. Now this, as will presently appear, is 84.82 grs., hence, 84.82—82.44 =2.38 is the excess due to the oxidation of the iron. If then x=iron in the metallic state, $52.2-x$=that in the form of oxide, and $x+(52.2-x)\frac{36}{28}$ must be equal to $52.2+2.38=54.58$, an equation from which we obtain x the metallic iron=43.87; and $(52.2-x)\frac{36}{28}$, the protoxide, =10.71 grs. Substituting then these numbers for 52.2, we obtain, as follows, the true composition of the portion of the meteorite dissolved by the aqua regia.

Sulphuret of iron	8.75
Iron	43.87
Nickel	2.28
Protoxide of iron	10.71
Magnesia	18.69
Lime	0.52
	84.82

This part of the analysis having been completed, it appeared to me that it would be interesting, before proceeding further, to examine the oxide of nickel above obtained, for the purpose of ascertaining whether it included any cobalt, these two metals being so frequently found associated in nature.

With this view 2.67 grs. of the oxide were dissolved in muriatic acid, and to the solution ammonia was added in excess, which threw down a very minute quantity of peroxide of iron. This latter being separated by filtration, caustic potash was added in considerable excess to the ammoniacal solution, and the oxide of nickel thus precipitated was separated by filtration. Through the filtered fluid sulphureted hydrogen was now passed. This, upon the application of heat, determined a small amount of dark precipitate, which, upon examination, proved to be sulphuret of cobalt. Thus it dissolved in nitric acid with the separation of sulphur; and the solution, when heated by the blowpipe with alumina, gave to this earth a beautiful blue colour. The quantity of the cobalt present was not determined, but its amount was undoubtedly extremely small.

We now return to the portion (B) of the aerolith, left unsolved by the nitro-muriatic acid. This portion of the stone, when dried upon the sand bath, was found to weigh 128.28 grs. Of this 114.12 were reduced by a red heat to 102.47. Hence, as 114.12 : 102.47 : : 128.28 : 115.18, the exact weight of the portion of the stone left undissolved by the acids.

The 102.47 grs. which had been exposed to heat were mixed in a platinum crucible with three times their weight of carbonate of potash, and fluxed at a strong red heat for twenty minutes. The fused mass was then transferred, by repeatedly boiling it with water, from the crucible to a porcelain capsule, dissolved in a dilute nitro-muriatic acid, and then cautiously evaporated to dryness. The dry residue having been now steeped for some hours with as much muriatic acid as was sufficient to moisten it, was then treated with distilled water, and collected on a double filter, on which the silex was washed, until the solution which passed through ceased to precipitate nitrate of silver. When dried upon the sand bath it weighed 94.71 grs.; 91.03 of this were reduced by a red heat to 66.87. Hence,

91.03 : 66.87 :: 94.71 : 69.57, the silex in the 102.47 of insoluble matter.

And, 102.47 : 69.57 :: 115.18 : 78.19, the total quantity of silex in (B).

To the washings of the silex, which were conceived to be sufficiently acid to admit of the omission of the sal-ammoniac without incurring the danger of precipitating any magnesia, caustic ammonia was added in excess, which threw down peroxide of iron, oxide of chrome, and with them what proved afterwards to be magnesia. These were collected as usual, and washed on a double filter, and when dried by a sand heat they weighed 31.37 grs.

The washings containing the magnesia with a trace of lime were boiled with carbonate of potash, and the whole being evaporated to dryness, and water again poured on, the precipitate was collected, and well washed on a pair of filters. When dried at 212° it weighed 38.17 grs. Of this 36.40 by a strong red heat were reduced to 17.40. Hence,

36.4 : 17.4 :: 38.17 : 18.24.

And 102.47 : 18.24 :: 115.18 : 20.50, the mixed magnesia and lime in (B).

Of the mixture of peroxide of iron and oxide of chrome with trace of magnesia, amounting to 31.37 grs., 31.07 were dissolved in muriatic acid, and muriate of ammonia being first added, the peroxide of iron and oxide of chrome were again thrown down by ammonia, which left the magnesia in solution. The oxides were collected, and washed on a single filter, and the washings, when boiled with carbonate of potash, gave a deposit of carbonate of magnesia, which, when washed, and dried at a sand heat, weighed 4.11 grs. 3.45 grs. of this were reduced by a red heat to 1.99. Hence,

3.45 : 1.99 :: 4.11 : 2.30, magnesia in the 31.07 grs.

And 31.07 : 2.30 :: 31.37 : 2.32, magnesia precipitated with the oxides.

And 114.12 : 2.32 :: 115.18 : 2.34, magnesia to be in this step obtained from B, the unsolved portion of meteorite.

The peroxide of iron and oxide of chrome were next washed off the single filter, and dissolved in muriatic acid. To the solution tartaric acid was then added in such quantity that upon subsequently adding ammonia in excess there was no precipitate. The iron was now thrown down as sesquisulphuret by the hydrosulphate of ammonia, and the precipitate, when collected on a single filter, was well washed with distilled water. It was then transferred to a porcelain capsule, in it decomposed by nitro-muriatic acid, and after filtering to separate sulphur, the solution was precipitated by the addition of ammonia in excess. The peroxide of iron, when dried on a sand bath, weighed 14.42 grs.; 13.23 grs. of this exposed to a red heat were reduced to 6.29. Hence,

13.23 : 6.29 :: 14.42 : 6.85, true weight of peroxide of iron.

31.07 : 6.85 :: 31.37 : 6.91

102.47 : 6.91 :: 115.18 : 7.76, the peroxide of iron in the entire of the fluxed portion of the meteorite. And

41 : 36 :: 7.69 : 6.98, the corresponding weight of protoxide, which is the form in which it exists in the stone.

The solution from which the iron was thrown down by the hydro-sulphate of ammonia, and which had a deep green colour, was concentrated on the sand bath, then filtered to separate sulphur, and finally evaporated to dryness, and ignited in a platinum crucible to destroy the tartaric acid. To the residue, which had a carbonaceous appearance, nitre was added, and heat being applied, the charcoal was burned off, and the oxide of chrome, at the same time, converted into chromate of potash, the whole was then acted upon by distilled water, and thrown upon a filter, which allowed the chromate of potash to pass through with carbonate of potash and excess of nitre, and detained a small quantity of insoluble matter, of a rusty colour, (magnesia, with deutoxide of manganese,) which was estimated, though in consequence of an accident not with any great precision, to amount to 1.08 grs.

The solution containing the chromate of potash was acidulated with muriatic acid, boiled, and treated first with alcohol, and next with an excess of ammonia, the former of which reduced the chromic acid to the state of chromic oxide; while the latter threw down the oxide from its combination with the muriatic acid. After desiccation on the sand bath it weighed 9.87 grs. Of these 8.97 were reduced by a red heat to 3.70. Hence, 8,97 : 3.70 : 9.87 : 4.07

the true weight of oxide of chrome in 31.07 out of 31.37 grains of the mixture chrome iron and magnesia; and therefore

31.07 : 4.07 : : 31.37 : 4.11

And 102.47 : 4.11 : : 115.18 : 4.61,

the oxide of chrome in 200 grains of the meteorite.

The results of the analysis of (B) are, therefore, as follows :—

Silex	78.19
Magnesia, a little lime, and a trace of oxide of manganese	23.92
Protoxide of iron	6.98
Oxide of chrome	4.61
Alkalies and loss	1.48
	115.18

If we collect from (A) and (B) the silex, the magnesia, the lime, the manganese, and the protoxide of iron, deducting from this latter 2.07 grains, the quantity associated in the stone with the 4.11 grains of oxide of chrome, we will have for the matrix the following constituents :—

Silex	78.19
Magnesia, &c.*	43.13
Oxide of iron	15.62
	136.94

Now if these numbers be divided by the respective atomic weights, we obtain the following results :—

$$\frac{78.19}{15.5} = 5.04$$

$$\frac{43.13}{20.7} = 2.08$$

$$\frac{15.62}{36} = 0.43$$

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* The lime and manganese being inconsiderable in amount, are incorporated with the magnesia.

But 5.04 is to 2.08+.43 almost exactly as 2:1. So that we thus arrive at the very interesting conclusion that the matrix of the stone is a bisilicate of magnesia and oxide of iron; that is, a true augite, or pyroxene.

This latter result, namely, the identification of the earthy base of the aerolith with a well known volcanic mineral, and the detection, for the first time, as far as I was aware, of cobalt, in association with the iron and nickel, appeared to me to be, *per se*, points of sufficient importance to justify me in laying them before the Academy. But even though nothing new had been disclosed by the chemical examination, I could not doubt but that an interest would be felt in the results of a carefully-made analysis of one of those mysterious bodies (one, too, which has fallen in our own country) whose existence was once denied, and in relation to whose source we have as yet little better than vague conjecture.

The analysis just detailed was completed early in March, and would have been communicated to the Academy at its general meeting of that month, but for the following circumstance.

Mr. Nathaniel Hone, of this city—a gentleman who has devoted himself, in my laboratory, with great zeal and considerable success, to the cultivation of analytical chemistry—while repeating, at my request, the chemical examination of this stone, drew my attention to the unusually light colour of the peroxide of iron which he had extracted, in the usual way, from the portion insoluble in acids, and which we have already designated by the letter (B). This, we found, was not due to alumine, for none of this earth could be extracted by potash, nor was the colour of the precipitate altered by digestion with the alkali. Neither did I suspect it, at the time, to be owing to magnesia, having been assured that the usual precautions were taken to prevent the precipitation of any of this earth upon the addition of the volatile alkali. With a view, therefore, to a further investigation of the matter, the peroxide of iron was well washed with distilled water, to remove all trace of potash; and, being then transferred to a porcelain capsule, it was heated, with a solution of oxalic acid gradually added, which dissolved the iron, and left a small quantity of a white precipitate. This latter, being well washed, dried, and ignited in a platinum crucible, gave a brownish residue, which was easily shown to be magnesia, coloured by deutoxide of manganese. Such was the pursuit that prevented me from sooner submitting the results of my analysis to the judgment of the Academy.

While engaged in this latter investigation, which I, at one time, supposed likely to eventuate in something more important, I had a visit from my friend Doctor Smith, one of our members, who informed me that he was just after reading, in the number of the Journal De Pharmacie for February, an extract from a paper by Berzelius, on the subject of meteoric stones. This information could not fail to interest me much, and having received from him, on the evening of the same day, the number of the journal in question, I opened it with the apprehension that I should find myself, as far as respected any novelty in the results of my analysis, anticipated by the great Scandinavian chemist. My suspicions proved to be well founded. Berzelius finds, in four distinct meteoric stones, the first of which fell at Blansko in Moravia, the second at Chantonnay in La Vendée, the third at Lontalax in Finland, and the fourth at Alais in France, as also in the meteoric iron of Elbogen, preserved in the museum at Vienna, and in the celebrated mass discovered by Pallas in Siberia, the following substances :—

1st. Cobalt, which I conceived I had been the first to notice. 2d. Tin. 3rd. Copper. 4th. Phosphorus, all in very small quantity, and in association with the alloy of iron and nickel. 5th. Potash and soda, also in very minute proportion.

Thus far it will be seen there is no contradiction between my results and those of Berzelius. The former, in fact, are, as far as they go, in complete accordance with the latter. There are, however, two important points, in reference to which we are at variance. In the first place, he assumes the chrome to be present in the form of an alloy with iron ; whereas I consider it as existing in its usual state, or in the form of oxide of chrome combined with protoxide of iron. As the article in the Journal De Pharmacie is but an extract from a German periodical, (Annalen der Physik und Chemie,) and merely gives results, but none of the details of the analytic processes, I am quite ignorant of the grounds of this opinion. The reasons that have suggested the view which I have myself adopted are—1st. That chrome often occurs in the form I have supposed. 2nd. That I am not aware of any such native alloy as that of chrome and iron. I have never seen it, and it is not described in books. 3rd. If such existed, the portion of the stone insoluble in acids would, while fluxing, in all probability injure or destroy the platinum crucible, an effect which I have never witnessed.

The other point of discrepancy between us, is one, at least in a theoretical point of view, of greater consequence. I have already stated, that according to my experiments, the matrix of the Limerick stone is augite, or a mixed bisilicate of magnesia and protoxide of iron. Berzelius finds the earthy base of the aeroliths he has analysed to be composed of bisilicates and silicates of the same bases, or, in fact, to be a mixture of augite and olivine, the former of which is insoluble, and the latter soluble in the diluted mineral acids. On this head it might be considered sufficient for me to observe, that the hypothesis I have made will alone represent my own results, and that as olivine alone occurs in some aeroliths, *e. g.* the meteoric mass of Pallas, so pyroxene, unmixed with olivine, may exist as the base of others. It would, however, be uncandid in me not to state my suspicion that the matrix of the stone I have examined, is in reality composed of two earthy minerals, differing, if not in composition, at all events in the circumstance of the one being soluble, and the other insoluble in acids. This circumstance I observed in my preliminary experiments upon the stone, and I have in more than one place alluded to it in the course of my analysis. Notwithstanding, therefore, the perfect correspondence of my theory with my quantitative results, I would wish, finding myself in opposition to such high authority, to be understood as propounding the theory with some degree of diffidence. I am indeed at present engaged in further researches, which will, I trust, shortly enable me to speak with more confidence on the subject.

The following analysis has since been made, and the results, it will be seen, are in accordance with the views of Berzelius.

72.76 grains of the meteorite, carefully deprived of all magnetic parts, were resolved, by a prolonged digestion with nitro-muriatic acid, evaporation to dryness, solution in acidulous water, and filtration, into two portions, A and B, the former being dissolved by the acid, and the latter left behind. The soluble portion A, analysed in the ordinary way, gave

Sulphuret of iron	4.34
Protoxide of iron	7.38
Oxides of nickel and cobalt . . .	0.24
Magnesia	13.38
	25.34

And the insoluble portion, B, yielded,

Silex	32.11
Protoxide of iron and oxide of chrome	5.91
Magnesia and a little lime . . .	9.43
	47.45

If then we exclude the pyrites, the following will be the component parts of matrix of meteorite:—

Silex	32.11
Oxides of iron, nickel, cobalt, and chrome	13.53
Magnesia, with a little lime . . .	22.81
	68.45

But

$$\frac{32.11}{15.5} = 2.07$$

$$\frac{13.53}{36} = 0.37$$

$$\frac{22.81}{20.7} = 1.10$$

Hence, the number of atoms of silex in the matrix of the stone is to the sum of the numbers of atoms of protoxide of iron and of magnesia, as 2.07 to $0.37+1.10$, or as 3 to 2.13. Now, as the atom of lime is greater than that of magnesia, and as the oxide of chrome and its associated iron do not exist in combination with silex, the latter number, 2.13, must be a little too high, so that the decimal part, at least, may be safely omitted. The number of atoms of silex will thus come out to be to the sum of the numbers of atoms of the bases with which it is combined, as 3 to 2; so that the stone is composed of an atom of a silicate, associated with an atom of a bisilicate, or, in other words, of an atom of olivine united to an atom of pyroxene. That such is the true composition of the portion of the meteorite under consideration, there can, I conceive, be no question, for the matrix is obviously composed of two distinct minerals, one of which, like olivine, is soluble, and the other, like augite, insoluble in the acids.

Some other rough experiments have shown that the relative quantities of the two minerals is different in different parts of the stone, and that the proportion of the olivine is in particular sometimes very small. In this way alone can I account for the results of my first analysis, which make the earthy basis of the meteorite an amorphous pyroxene.